Glass and Ceramics Vol. 65, Nos. 9 – 10, 2008

SCIENCE FOR GLASS PRODUCTION

UDC 666.1.022:622.788

EFFECT OF FINELY DISPERSE CULLET ON GLASS BATCH BRIQUETTING

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Translated from *Steklo i Keramika*, No. 9, pp. 14 – 18, September, 2008.

All of the drawbacks of the ordinary traditionally prepared cullet-containing batch are the cause of constant improvement of batch preparation technologies. It was shown that briquetting of the batch is a function of the cullet content and especially the cullet particle size.

Use of cullet as valuable mineral stock in glass batch is one method for enhancing the glass-melting process and saving power and raw material resources [1, 2]. As glass making practice shows, despite the fact that one cause of the inadequate homogeneity of glass is the cullet in the batch itself, it is now widely used [3].

The granulometric composition is a decisive condition for successful glass melting when cullet is used, so that great attention is now being focused on methods of preparing it, the particle size in particular. It should be noted that the particle size of the cullet in free-flowing batch has varied within very wide limits over the past 70 years — from fractions of a millimeter to 100 mm, while the basic size of particles of other components is less than 1 mm. Preference is now given to a maximum cullet particle size of 30 mm [4, 5].

It was found that homogeneity of the batch is a function of the ratio of the grain size of the individual constituent parts of the batch, while the homogeneity of the glass is additionally a function of the method of loading the batch and cullet into the furnace [6, 7]. All of the drawbacks of the usual traditionally prepared batch are the cause of constant improvement of batch preparation technologies. There are now several methods of batch preparation. The selection and effectiveness of a method are primarily a function of the granulometric composition and degree of moldability of the initial batch [8]. One method of condensing the batch, which can be applied to any batch, is briquetting.

The analysis of studies of preparation of briquettes from a cullet-containing batch showed that this batch preparation practice exists [9], but has been inadequately studied, and for this reason is of interest.

To investigate the possibility of briquetting glass batches with bottle glass cullet of different compositions, the studies were conducted in two stages. In the first stage, it was necessary to study the effect of the cullet particle size on the briquetting process, and in the second stage, to see how the cullet content in the batch affects the compacting and strength of the briquettes. To reach this goal, it was necessary to solve the following problems: to select the briquetting parameters (molding pressure and moisture content) of two types of bottle glass batches, to investigate the effect of the cullet particle size and content in the batches on the density and strength of the briquettes obtained with a three-factor experiment, and to compare the results of the studies.

The chemical compositions of the bottle glasses were used as the base:

colorless (%[2]): 72.10 SiO_2, 2.20 Al_2O_3, 6.25 CaO, 4.00 MgO, 15.00 Na_2O, 0.15 Fe_2O_3;

green (%): 70.12 SiO_2, 2.50 Al_2O_3, 10.00 CaO, 2.00 MgO, 15.00 Na_2O, 0.26 Cr_2O_3, 0.12 Fe_2O_3.

The following raw materials were used to make up the batches:

for the colorless glass, the quartz sand, chalk, dolomite, feldspar, calcined soda, soda-sulfate mixture, and colorless bottle glass cullet used at Astrakhan'steklo Co.;

for green glass, the molding quartz sand, blast-furnace slag from Cherepovets Metallurgical Plant and Portachrom A-38, nepheline stock soda, grade 1 conversion chalk, sulfate, and green bottle glass cullet used at Chagodoshchenskii Glass Works Ltd.

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[2] Here and below: mass content.

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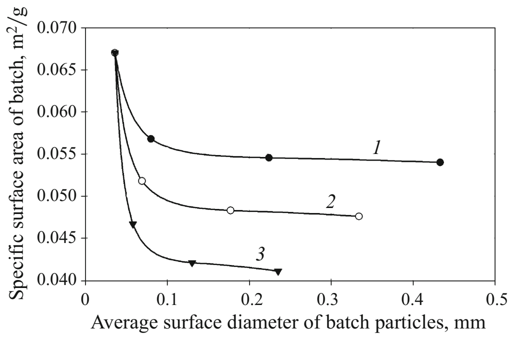

Fig. 1. Effect of the average-surface diameter of batch particles on its specific surface area in incorporation of 20% (*1*), 30% (*2*), and 40% (*3*) cullet.

Since the particle size of the raw materials for these batches was approximately 1 mm, the cullet used for the briquetting process was ground and then sieved to separate the fractions close to the basic size of the sand particles (0.08 – 0.25, 0.40 – 0.63, and 0.80 – 1.25 mm).

The specific surface areas of each cullet fraction were calculated (separately) to determine the contribution of the cullet added to the change in the specific surface area of the cullet-containing batch (Table 1). The calculation was performed with the value of the average-surface cullet particle diameter:

$$D_{\text{av}}^{\text{sur}} = \frac{100}{\sum \frac{\Delta Q}{D_{\text{cp}}}},$$

where $D_{\text{av}}^{\text{sur}}$ is the average-surface diameter of the cullet particles, mm; Q is the cullet particle content, fractions; D_{av} is the average size of the cullet fraction, mm.

In calculating the average-surface cullet particle diameter, a 0.01 mm step was used for the change in the particle size within each fraction, and the mass content of the particles ΔQ was the same.

The specific surface area was calculated with the equation:

$$S_{\text{sp}} = \frac{60{,}000}{\rho_{\text{re}} D_{\text{av}}^{\text{sur}}},$$

where S_{sp} is the specific surface area of the cullet, m^2/g; ρ_{re} is the density of the glass, kg/m^3.

TABLE 1

Cullet particle fraction, mm	Average-surface particle diameter, mm	Specific surface area, m^2/g
0.08 – 0.25	0.147	0.01630
0.40 – 0.63	0.506	0.00475
0.80 – 1.25	1.030	0.00233

The specific surface area of the initial batch, i.e., with no cullet, was determined on a PMTs-500 instrument for the further calculations. The real density of the batch was calculated with the value of the real density of the components of the batch according to the law of additivity:

$$\rho_{\text{re.b}} = (\rho_1 C_1 + \rho_2 C_2 + \ldots + \rho_n C_n),$$

where $\rho_{\text{re.b}}$ is the real density of the batch, kg/m^3; ρ_1, ρ_2, ..., ρ_n is the density of each component of the batch, kg/m^3; C_1, C_2, ..., C_n is the content of each component of the batch, fractions.

After calculating the real density of a colorless glass batch, 2690 kg/m^3, we determined the specific surface area of the initial batch, 0.067 m^2/g. The data from calculating the specific surface area and the average-surface diameter of the initial batch and batch with cullet added in the amount of 20, 30, and 40% are reported in Table 2.

The effect of the cullet particle size on the change in the specific surface area of batch with a different cullet content is shown in Fig. 1. The analysis of the dependences allows drawing a conclusion concerning the nonproportional decrease in the specific surface area with an increase in the average-surface particle diameter. The values obtained can be described with a sufficient degree of accuracy by the equation:

$$S_{\text{sp}} = \frac{a - bD_{\text{av}}^{\text{sur}}}{1 - cD_{\text{av}}^{\text{sur}}},$$

where a, b, and c are approximation coefficients equal to 0.050, 1.870, and 34.900 for 20% cullet content; 0.038, 1.870, and 40.000 for 30% content; 0.022, 1.870, and 46.400 for 40% cullet content.

An active multifactorial experiment based on the central composite rotatable design CCRD-2 for bottle glass batches was used to study the combined effect of a number of factors on the batch briquetting process. The compressive strength σ and density ρ were used as the quality criterion and the

TABLE 2

Cullet particle size, mm	Amount of cullet added, %	Average-surface diameter of batch particles, mm	Specific surface area of batch, m^2/g
Initial batch	–	0.036	0.0670
0.08 – 0.25	20	0.058	0.0569
0.40 – 0.63	20	0.130	0.0545
0.80 – 1.25	20	0.235	0.0541
0.08 – 0.25	30	0.069	0.0518
0.40 – 0.63	30	0.177	0.0483
0.80 – 1.25	30	0.334	0.0476
0.08 – 0.25	40	0.080	0.0467
0.40 – 0.63	40	0.244	0.0421
0.80 – 1.25	40	0.433	0.0411

TABLE 3

Composition	Coded variables*			Parameters			Strength of briquettes, MPa, for fabrication of		Density of briquettes, kg/m^3, for fabrication of	
	X_1	X_2	X_3	X_1	X_2	X_3	colorless glass	green glass	colorless glass	green glass
1	– 1	– 1	– 1	5	7.5	20	0.950	0.400	2290	1980
2	– 1	– 1	1	5	7.5	40	0.840	0.390	2320	1975
3	– 1	1	1	5	17.5	40	1.140	0.360	2400	1920
4	– 1	1	– 1	5	17.5	20	1.175	0.430	2410	1990
5	1	– 1	– 1	9	7.5	20	1.075	0.410	2320	2020
6	1	– 1	1	9	7.5	40	0.740	0.340	2320	1960
7	1	1	– 1	9	17.5	20	1.275	0.580	2390	2100
8	1	1	1	9	17.5	40	1.010	0.380	2340	2000
9	– 1	0	0	5	12.5	30	1.225	0.310	2425	1960
10	1	0	0	9	17.5	30	1.225	0.520	2380	2030
11	0	0	– 1	7	12.5	20	1.300	0.410	2430	2018
12	0	0	1	7	12.5	40	1.120	0.370	2415	1985
13	0	– 1	0	7	7.5	30	1.000	0.260	2340	1940
14	0	1	0	7	12.5	30	1.250	0.310	2420	1970
15	0	0	0	7	17.5	30	1.230	0.360	2415	1980

* X_1) moisture content, %; X_2) molding pressure, MPa; X_3) cullet content, %.

molding pressure *P*, batch moisture content *W*, and cullet content were used as the optimization criteria (Table 3).

We prepared 15 colorless and green bottle glass batch compositions in the present study. Three parameters were varied — the moisture content (5, 7, and 9%), briquette molding pressure (7.5, 12.5, and 17.5 MPa), and in the first stage, the cullet particle size and in the second stage, the cullet content in the batch (20, 30, and 40%). Briquettes were made from the prepared compositions by molding in a PG-500 hydraulic press (see Table 3).

It was found that the cullet particle size did not affect briquetting as strongly as the cullet content. A dispersion analysis of the sand used was performed based on this and the cullet fraction close to the basic sand particle size, 0.40 – 0.63 mm, was selected for the subsequent studies.

The briquettes obtained had a defined moisture content and low strength, so that subsequent heat treatment as a strengthening method was necessary. Drying in two stages was selected: first for 1 h in air, and then at 150°C with holding for 2 h in a drier.

As a result of mathematical processing of the results of the experiment, regression equations were obtained for two bottle class compositions that describe the dependence of the density and compressive strength of the briquettes on the cullet content, batch moisture content, and molding pressure:

for colorless glass batch:

$$\rho = 2438.6 - 5.2X_1 + 37.7X_2 - 3.1X_3 - 19.4X_1^2 - 61.7X_2^2 - 17.9X_3^2 - 13.9X_1X_2 - 9.6X_1X_3 - 9.6X_2X_3;$$

$$\sigma = 1.265 - 0.0001X_1 + 0.128X_2 - 0.089X_3 - 0.044X_1^2 - 0.152X_2^2 - 0.059X_3^2 - 0.008X_1X_2 - 0.058X_1X_3 + 0.023X_2X_3;$$

for green glass batch:

$$\rho = 1968 + 22X_1 + 23.2X_2 - 18.3X_3 + 16.6X_1^2 - 12.2X_2^2 + 31.3X_3^2 + 20.9X_1X_2 - 14.6X_1X_3 + 0.8X_2X_3;$$

$$\sigma = 0.307 + 0.038X_1 + 0.053X_2 - 0.027X_3 + 0.046X_1^2 + 0.001X_2^2 + 0.085X_3^2 + 0.03X_1X_2 - 0.015X_1X_3 - 0.005X_2X_3,$$

where ρ is the density of the briquettes, kg/m^3; σ is the strength of the briquettes, MPa.

TABLE 4

Cullet content, %	Batch moisture content, %	Molding pressure, MPa	Briquette density, kg/m^3	Briquette strength, MPa	Decrease in briquette strength, %
20	7.75 – 8.75	13.5 – 14.5	2430 – 2440	1.325 – 1.350	–
30	5.75 – 8.25	13.5 – 16.0	2420 – 2430	1.275 – 1.300	3.77
40	5.00 – 6.75	13.5 – 16.5	2410 – 2420	1.140 – 1.160	13.96

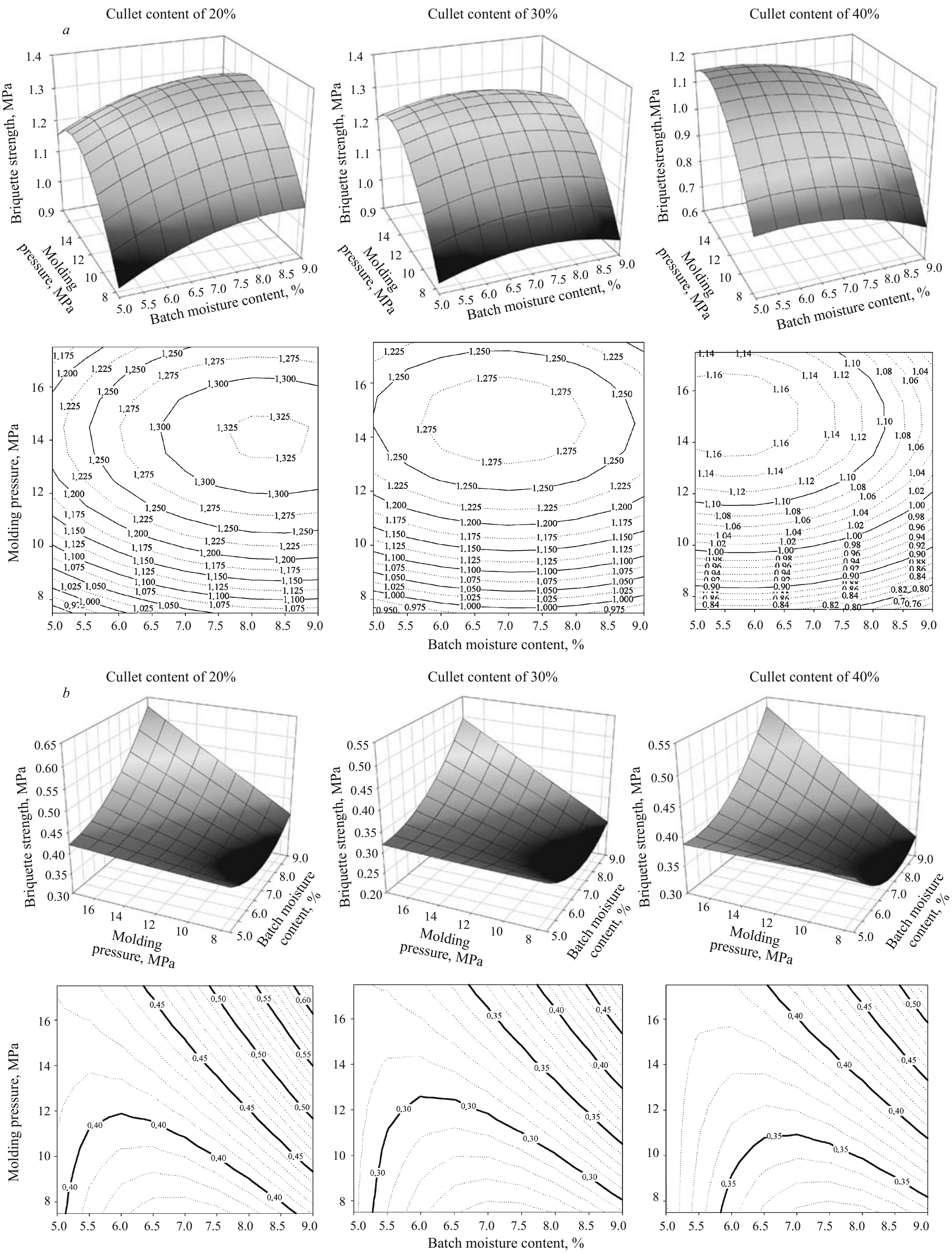

Fig. 2. Strength of briquettes from colorless (*a*) and green (*b*) bottle glass batches as a function of the molding parameters.

Graphs of the strength of the briquettes as a function of the batch moisture content, amount of cullet, and molding pressure were plotted with the regression equations obtained (Fig. 2). An analysis of the strength of the briquettes showed that briquettes from the colorless glass batch have a density and strength 1.5 times higher than for briquettes from green glass. This is primarily due to the different moldability modulus indexes of the batches used. The moldability modulus is lower the better the batch is compacted. This index is equal to 0.2 for the colorless glass batch and 0.4 for the green glass batch. This is because the green glass batch contains 18% slag, which is neither a hygroscopic nor a plastic material, and this in turn does not increase the cohesive force of the batch particles in compacting, and as a result does not ensure the strength of the briquette.

Figure 2 shows that when colorless glass batch is used, there is a certain region of the briquetting process, if the optimum molding parameters are used, in which the briquettes have the maximum strength. The optimum molding region for glass with colorless glass cullet is reported in Table 4.

The effect of the batch moisture content and molding pressure on the briquette strength was investigated. It was found that the character of the effect of these parameters differs for the two types of batch. Average molding parameters (7% moisture content, 12.5 MPa molding pressure) were required for the colorless glass, since when the batch content was above 7%, excess moisture appeared and was easily removed from the briquette and mold. Increasing the molding pressure after removing the load on the molded material caused formation of microcracks in the layer of the molded pieces, which reduced the strength of the briquettes. The maximum molding parameters (9% moisture content, 17.5 MPa molding pressure) were necessary for the green glass batches, and this eliminated the presence of an optimum region but indicates the possibility of further increasing the molding pressure above 17.5 MPa and using another binder to increase the strength of the briquettes. The rational batch molding indexes are reported in Table 5.

The direct dependence of the small reduction in the strength of the briquettes with an increase in the cullet content in the batch to 30% and a more significant decrease with a cullet content of 30 to 40% were found from the results of briquetting the two types of batches (see Table 5).

Based on these studies, we can draw a conclusion concerning the possibility of briquetting bottle glass batches with glass cullet. Despite the fact that the strength of the briquettes decreases with an increase in the cullet content in the batch, the values obtained are sufficient for shipping briquettes to the glass-melting furnace without destroying them and their subsequent use in the glass melting process.

TABLE 5

Bottle glass	Cullet content, %	Batch moisture content, %	Molding pressure, MPa	Briquette strength, MPa	Decrease in briquette strength, %
Colorless	20	7	12.5	1.300	–
	30	7	12.5	1.250	3.85
	40	7	12.5	1.120	13.86
Green	20	9	17.5	0.580	–
	30	9	17.5	0.520	10.34
	40	8	17.5	0.480	17.24

The use of a batch with cullet prepared by this method is also economically advantageous. All costs for crushing the cullet and installing batch briquetting equipment can be justified. In compacting batch, the reactions between its components begin in the solid state. In the given case, in compacting the batch, the cullet particles, like the grains of SiO_2, are coated with a thin layer of alkali and cohesion of the particles is better as a result of its moistening. This allows reducing the batch melting time, the glass melting process takes place at lower temperatures with a reduction in the power consumed for melting the glass, and the use of finely disperse cullet decreases the number of defects in the finished glass and increases its homogeneity, on which the strength, thermal stability, and other properties of glass articles are dependent.

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